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ULTRASONIC GRINDING TECHNIQUES IN MICROMINIATURIZATION

John Krawczyk

28 July 1961

DIAMOND ORDNANCE FUZE LABORATORIES
ORDNANCE CORPS ● DEPARTMENT OF THE ARMY
WASHINGTON 25, D. C.

ORDNANCE CORPS

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FOR THE COMMANDER
Approved by:

R. DeMasi

R. DeMasi
Chief, Division 800

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ABSTRACT

Ultrasonic impact grinding techniques are shown to be extremely useful in the fabrication of microcircuit substrates and other specialty component parts. Pertinent parameters of machine operation and tool design are discussed and detailed examples of applications are given. These include the fabrication of: (1) sections of glass only 0.005 in. in thickness, (2) multihole substrates, (3) Hall measurement specimens, (4) tiny toroids, and (5) spiral grooves.

1. INTRODUCTION

Glasses and ceramics are frequently employed as substrates upon which to form microcircuits. Methods by which these materials can be processed into specialized shapes include diamond sawing, molding, diamond machining, and sandblasting.

Although diamond sawing suffices when a flat substrate with straight sides is required, circular sections and/or the addition of holes and cavities require more elaborate machining methods. Molding is an adequate technique for quantity production of microcircuit substrates but it does not permit the dimensional versatility required in the design and development of prototype models. Machining with diamond-tipped tools is time-consuming and hence extremely expensive. It is usually resorted to only where single, precision units are being produced. Sandblasting allows a certain freedom for incorporating holes and cavities wherever desired but is also time-consuming and difficult to control to tight tolerances.

In the past two decades, development work in the field of ultrasonics has resulted in a variety of ultrasonic machines which have industrial uses. One of these machines, the ultrasonic impact grinder, is of particular interest since it affords a versatile and economic means of forming a variety of shapes in hard, brittle materials such as glass and ceramic.

Ultrasonic impact grinding techniques have been used in the engraving and drilling of semi-precious stones for the jewelery industry (ref 1), the cutting apart of mass-produced semiconductor devices (ref 2), the fabrication of cheap infrared absorption cells (ref 3), the fabrication of extrusion dies (ref 4), and many other applications (ref 5 and 6).

Two companies in the U. S. A. manufacture ultrasonic impact grinding machines: (1) Sheffield Division of Bendix Corporation, and (2) Raytheon Co. One of the Raytheon machines is a 100-w model particularly adaptable to working on small pieces. The Sheffield machines are significantly larger and the one at DOFL is employed primarily for heavy duty machining.

In 1959, DOFL began to investigate ultrasonic impact grinding techniques for fabricating microcircuit substrates and other special component parts. DOFL has machines made by both of the companies listed above but the work reported in this paper was all done on a Raytheon Model 2-334 (ref 7 and 8).

The report that follows is divided into three major sections. The first two sections deal with the machine itself and with the factors deserving attention in its operation, e. g. tools, abrasive slurries, and machine settings. Although the majority of the information given in these sections is not new, particular attention is given to those aspects of ultrasonic impact grinding that are applicable to the field of microelectronics. Some illustrative experimental data obtained on the machine at DOFL are included. The third section of the report describes in detail the design and construction of tools for the fabrication of special pieces required at DOFL.

2. MACHINE DESCRIPTION

The mechanism of ultrasonic impact grinding is a relatively simple one. A slurry of abrasive grit and water is flowed across the top of the work to be machined and a tool is caused to vibrate in a vertical plane in this slurry. The vibration of the tool forces the abrasive grit to pit and chip the work under the tool, and finally to form a cavity in the piece identical with the geometry of the tool.

The impact grinder employed in the work to be described herein is shown in figure 1. It consists essentially of four parts: (1) the electronic power supply, left, (2) the head, top right, (3) the pedestal, center right, and (4) the slurry system.

The power supply contains a power oscillator which drives a magnetostrictive transducer in the head. The power supply can be adjusted to a frequency at which the tool holder will resonate.

Figure 2 is a close-up view of the head and pedestal. Pertinent features are labeled for reference.

The head contains the transducer, a blower for cooling the transducer, a counterbalanced suspension system for the tool holder, the tool holder and attached tool, and the controls and gages for setting grinding pressure and monitoring the depth of cut.

The pedestal contains a tray in which a table for positioning the work piece is located.

The slurry system consists of a pump (not shown in photograph), hoses, and nozzles, which are attached to the pedestal. As the grinding proceeds, the pump continually delivers slurry via the hoses and nozzles to a position immediately beneath the tool. Excess slurry drains into the tray, and back into the pump, and is recirculated.

3. OPERATION

A complete operation consists of the following steps:

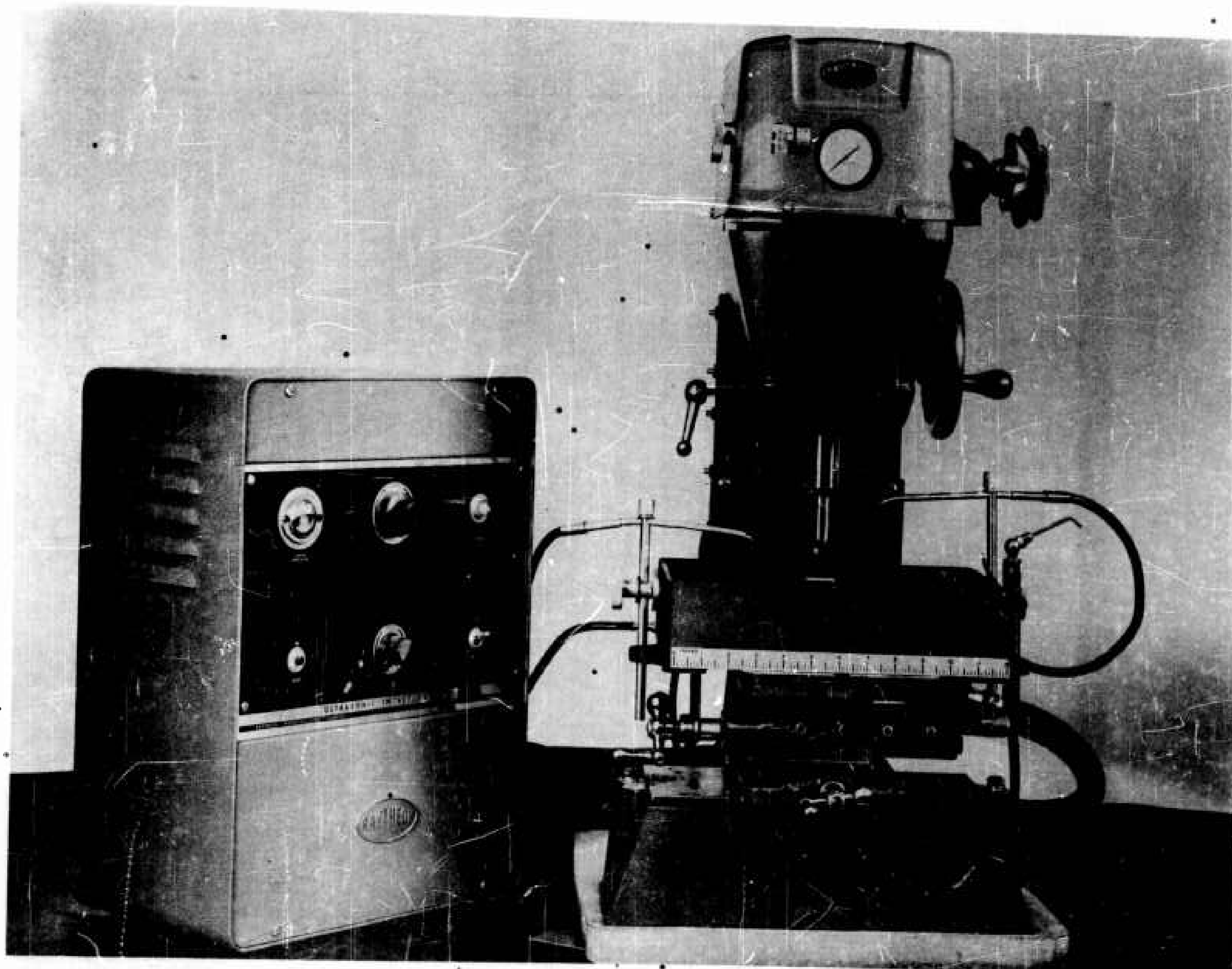

Figure 1. An ultrasonic impact grinder.

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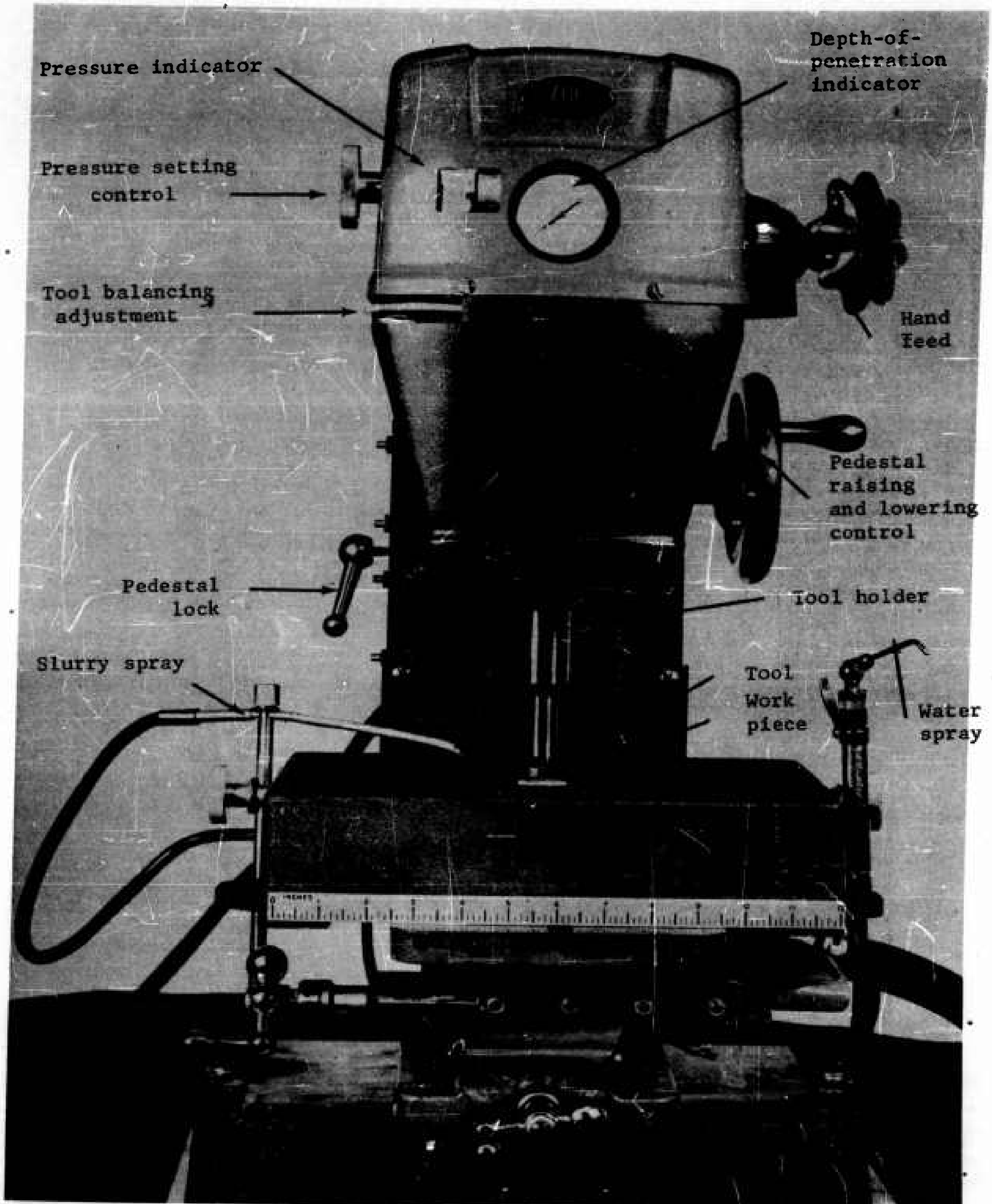

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Figure 2. Close-up view of head and predestal of ultrasonic impact grinder.

1. A tool is fabricated and attached to the tool holder.

2. The work piece, which may be attached to a backing plate, is aligned beneath the tool.

3. An abrasive slurry is introduced onto the work piece.

4. Pressure, frequency, and power are adjusted and the tool grinds through the work piece.

The pertinent details associated with each of the above steps are described in the sections that follow.

3.1 A tool is fabricated and attached to the tool holder.

The tool can be of any shape since it merely impacts on the film of slurry and does not rotate. The primary requirement in choice of material from which to fashion a tool is that it have a significantly lesser rate-of-wear than that of the work piece.

During impact grinding, both the tool and the work piece are worn down. The wear-ratio of the two materials is defined as the ratio between the loss in length of the tool and the depth of the cavity cut in the work piece. For example, for a glass work piece and a stainless steel tool, it was found that the tool was shortened by 0.001 in. after a cavity 0.100 in. in depth had been formed in the glass; hence in this case, the wear-ratio was 1 to 100.

Wear-ratios for tools made from stainless steel, cold rolled steel and brass, when applied to glass and steatite ceramic, were determined experimentally and are given in Table 1.

Table 1. Wear ratios[a/] between various tool[b/] materials and various work pieces

Material	Wear ratio vs Glass	Wear ratio vs Steatite
Stainless steel	1:100	1:40
Cold rolled steel	1:100	1:35
Brass	1:40	1:10

[a/] Ratio of loss of length of tool to depth of cut.

[b/] All tools were 1/4 in. in diameter, were attached to a tapered tool holder, and were used with No. 320 grit at 1-1/2 lb pressure.

Selection of tool material must take into consideration the anticipated length-of-run. Stainless steel is preferable for long-time grinding operations. However, drill rod and ground tool stock have been found adequate for virtually all applications encountered to date. The former was used to make tools to cut both round and square cavities in the substrate, and the latter was used to make tools to cut out the substrate itself. It is even possible to use a metal as soft as brass in a case where only a few pieces are being prepared.

The primary shaping action takes place where the work piece encounters the bottom of the tool. To produce a cavity or hole of a specified size, the tool must be undersized by a figure equal to twice the diameter of the particles of abrasive grit in the slurry. For example, the particle size of No. 320 grit is 0.0013 in., and the length and the width of a square-bottomed tool, or the diameter of a round-bottomed tool, to be used with this grit must be reduced by 0.0026 in. to give a cavity of the required size.

Tools required to cut holes of a variety of shapes are fabricated with downward-projecting studs of appropriate dimensions. The studs are attached to a plate, which is attached to the tool holder. The joint between the plate and the tool holder must be brazed because of the stresses to which it is subjected. The joints between the plate and the studs can usually be made with solder or with cement, provided the tool holder has previously been brazed to the plate. Simple tools are usually assembled by first drilling the tool plate to receive the individual studs, then brazing the plate to the tool holder, and finally soft soldering or brazing the studs into the holes in the plate. Complex tools are usually assembled by brazing the tool plate to the tool holder, and at the same time brazing the studs to the tool plate.

It is advantageous that the cutting area of each of the individual studs assembled on one tool be approximately the same. Otherwise, it is necessary to resharpen all the large-area studs when the smallest, (most wear-prone) stud requires resharpening. It is also important that: (1) no tool overlap the base of the tool holder by more than 1/32 inch, and (2) that excess solder be removed from the tool holder after the brazing operation. The former fault will stress the joints and may cause a rupture in the tool, while the latter one unbalances the tool and reduces it resonance.

Tool wear and time for drilling are minimized by cutting only the outline of the hole and permitting the cut-out center to fall out when the cut is completed. This technique is known as trepanning and it can be used for making any enclosed shape. It is particularly useful when the hole is large enough to permit a tool of substantial wall thickness to be used. A wall thickness of about 0.020 in. has been found useful in many cases. Factors affecting the choice of wall thickness of the tool include the work, the tool materials, the number of pieces to be made, and the dimensional tolerances to be held.

When the tool is slightly worn, dimensions of through holes can be retained by increasing the depth of the drilling into the backing plate, so that the bottom of the hole in the work piece is formed by unworn sections of the tool. Even so, resharpening will eventually become necessary and, for this reason, tool tips are usually made longer than originally needed so that worn tips can be machined or ground down. Before sharpening, fragile tool sections are supported by wax which is poured into recesses in the tool to present a solid surface to the grinder. Sharpening of tools for counterbored or stepped holes is facilitated by designing the tools such that all studs for each given depth of penetration are mounted on a single tool plate. Then, grinding to the different depths is done in separate operations.

3.2 The work piece is attached to a backing plate and aligned beneath the tool.

A backing plate is required to support fragile work. In addition, a backing plate eliminates chipping of the work piece at the point where the tool re-emerges after forming a through hole. Also, it permits deep penetration of the tool in cases where a worn tool is being employed and tolerances must still be maintained.

The characteristics and availability of glass make it an excellent material for use as a backing plate. Where practical, the backing plate is made in the same dimensions as the work. It is attached to the work by means of a film of wax (Dennison A-14, for example) applied while the work and backing plate are hot.

The assembled piece is dropped into a mating receptacle in a metal plate fixed under the tool. This receptacle facilitates exact reproduction in pilot-lot and production runs. Alternatively, the assembled piece can be pushed against stops mounted on the fixed plate. In the latter case, after the tool is brought down on the work, and the cutting started, the piece is held accurately in position by the sides of the cut. When the job is finished, the work and backing plate are separated by use of an appropriate solvent.

When cavities must be made, uniformity of thickness of the wax film is of importance, partly to obtain straight sides and also to arrive at the proper machine setting to give the required depth. It has been found that when the backing plate and work piece are heated on a hot plate to a temperature of 120°C, their surfaces rubbed with a stick of wax, and the two pieces then joined, a uniform wax film of thickness 0.001 in. is produced.

3.3 An abrasive slurry is introduced onto the work piece.

A slurry is usually prepared by mixing 2 parts by volume water into 1 part by volume abrasive grit (boron carbide). The slurry is fed through tubing to a nozzle from which it flows onto the work. The ideal situation is for the slurry to flow underneath the tool, into the cut, and then across the work surface. As grinding proceeds, the abrasive capability of the grit particles deteriorates, and the slurry is adulterated with less abrasive particles of the work and of the tool. Eventually, the slurry must be discarded and replaced with new slurry.

The necessity of using grit sizes finer than 0.0013-in. diameter for extensive areas of work, for deep cuts, and for close dimensions of fine contours has been noted. However, finer grits do not always insure a flow of slurry over the entire work surface. Such coverage has been obtained by using the tool itself as a nozzle. The slurry flows down a passage drilled through the center of the tool holder and tool plate and is forced out radially across the work. The slurry is pumped into this passage via a stem fitted into a transverse hole drilled from the outside of the tool holder. This transverse hole must be located at the node of the tool holder where the holder is motionless even when the ends are vibrating.

3.4 Pressure, frequency, and power are adjusted and the tool grinds through the work piece.

In conventional machining methods, a machine is set to remove material from the work piece at a uniform rate. In impact grinding, the tool pressure, rather than the cutting rate, is kept constant.

Pressure is automatically maintained at the level preset by the operator. The optimum level is that which will result in maximum cutting rate without work breakage or tool failure. An increase in pressure above the optimum will actually reduce cutting speed. Selection of optimum pressure for a given job is principally a matter of operator experience, skill, and "feel".

The length and mass of the tool holder and tool are of utmost importance, since they determine the resonant frequency of the system. Most efficient and effective operation of the impact grinder is obtained only when the driving frequency is adjusted to the self-resonant frequency determined by these factors. For this reason, the driver power is adjustable to frequencies between 22 kc and 28 kc. The operator uses the machine's visual tuning indicator (magic eye tube) and/or aural indications to obtain proper tuning. In the latter case, the tool cone is immersed in a beaker of water and the tuning knob adjusted to give maximum cavitation noise. Raytheon reports that this tuning method subjects the tool to stress similar to that encountered in actual grinding of the work piece.

Maximum cutting rates result from maximum amplitude (0.004 in.) or stroke of the tool. For the work reported here, this amplitude was often reduced because of the fragility of the work piece or of the tool. The amplitude is a function of the power applied to the head. The speed, therefore, is not fixed but is varied with the material, tool area, amplitude, and pressure used. Figure 3 shows, for stainless steel tool studs and a ceramic work piece, the inverse relationship between the diameter of the tool and the cutting rate.

Electronic component parts are often inserted in holes in insulators but sometimes cavities rather than through-holes are desired to retain these parts. Impact grinding is readily adaptable to making cavities. They are produced by grinding only as far as the desired depth, as indicated on the tool travel dial indicator. Tapers, counterbores, and holes with stepped sides are also within the capability of this versatile machine.

4. APPLICATIONS

The foregoing material has supplied background on the use of the ultrasonic impact grinder. Experience is essential in its successful use but the most valuable experience is gained from solution of problems arising in the course of designing and fabricating the tools themselves.

Following is a discussion of how eight problems were laid out and solved. In each case, unique techniques, both in toolmaking and in cutting,

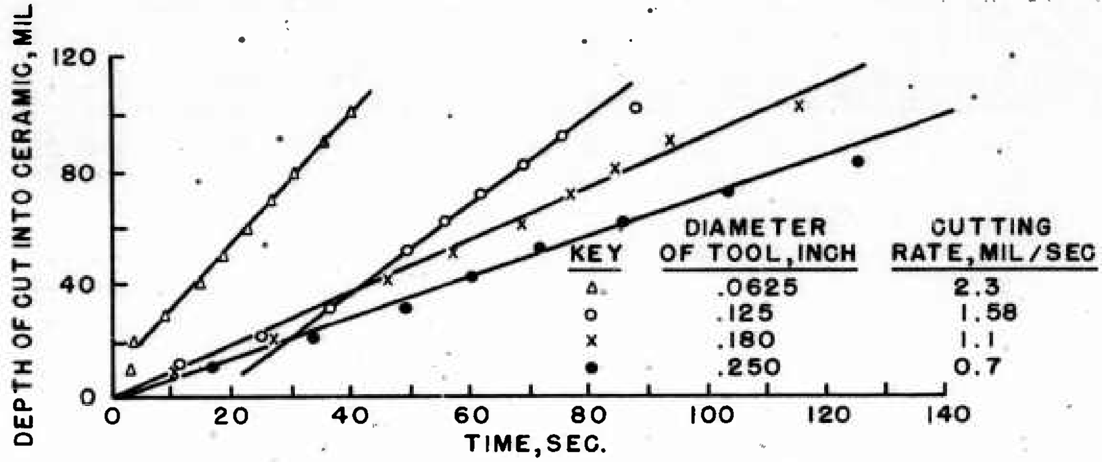

Figure 3a. Determination of cutting rate of stainless steel tools of varying sizes into ceramic.

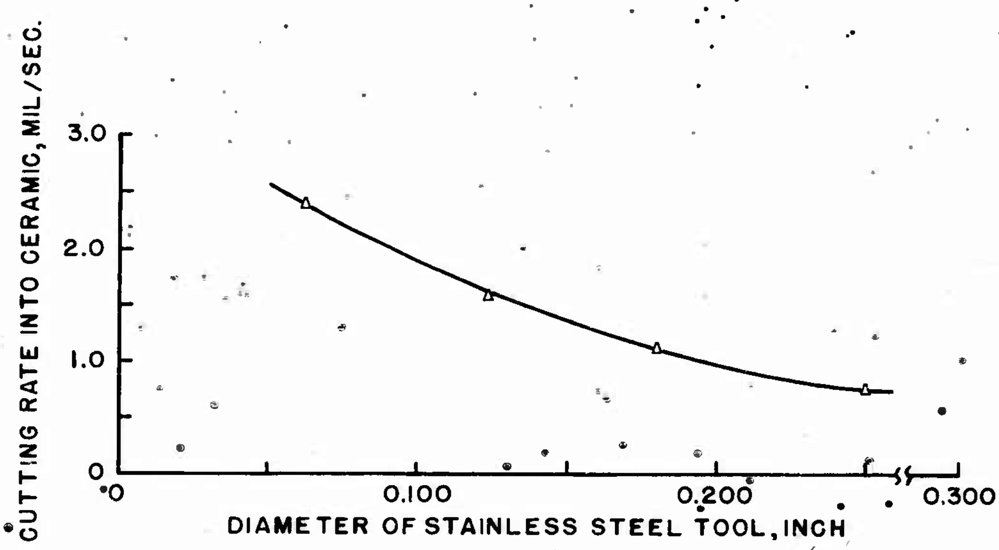

Figure 3b. Cutting rate of stainless steel tools into ceramic as a function of tool diameter.

are described. However, construction of the tool is generally the principal problem, and the ingenuity used in this phase of any job will in many cases determine the success of the technique.

4.1 Grinding to thin sheets.

Many applications for glass and ceramic require these materials in the form of thin sheets. In this particular job, a one-inch-square piece of glass, 0.005 in. in thickness, was required.

As can be seen in figure 4, a 3/4-inch-diameter flat-bottomed tool covers an entire one-inch-square work piece if the piece is rotated around its center while the tool is offset from center. Drill rod was used for the tool material because tool wear against glass is not a problem. Glass 0.025 in. in thickness was available. A one-inch-square of it was attached in the center of the rotatable platform by means of wax, care being taken to insure that the coat of wax was of uniform thickness. The center of the platform was then aligned with an outside edge of the tool, as shown in figure 4. Slurry made from grit No. 320 was pumped from a single nozzle across the work piece, and the platform was rotated around its center. Grinding progressed until the desired thickness was obtained. A pressure of 1.5 lb was used at full power. Approximately 10 min were required to remove a thickness of 0.020 in. and yield a wafer of thickness 0.005 in.

It is interesting to note a variation of this technique: a second cut with a smaller tool, or with the platform aligned with the center of this same tool, will produce a depression in the work piece, framed by a lip.

4.2 Multiple holes in ceramic plate.

It was desired to grind two round holes and four square holes through a 0.6-in. square ceramic plate 0.020 in. in thickness. The tool and product are shown on the left-hand side of figure 5.

Drill rod was used for the studs for both the round and the square holes. It was drilled out to permit trepanning the holes and to give a saving in grinding time. In the case of the square studs, the base of each was left round, but the cutting end was milled flat on the four sides to yield the desired dimensions. In drilling out these studs, it is desirable to retain a wall thickness of at least 0.020 in. at the thinnest points.

Six holes were drilled in the tool plate at the required positions. These holes were dimensioned to accept the bases of the studs with a minimum of play. Then the tool plate was brazed to the tip of the tool holder. Next, the studs were inserted in their proper positions, facing up, and soft soldered in place. Note that the higher temperature brazing operation was performed first, at the joint between the holder and the plate where its use was required, and that soft-soldering of the tools to the tool plate followed. Finally, the tool was sharpened by grinding the cutting ends to the same length.

The work was secured by means of wax to a glass backing plate of the same size; this assembled piece was then dropped into a mating receptacle

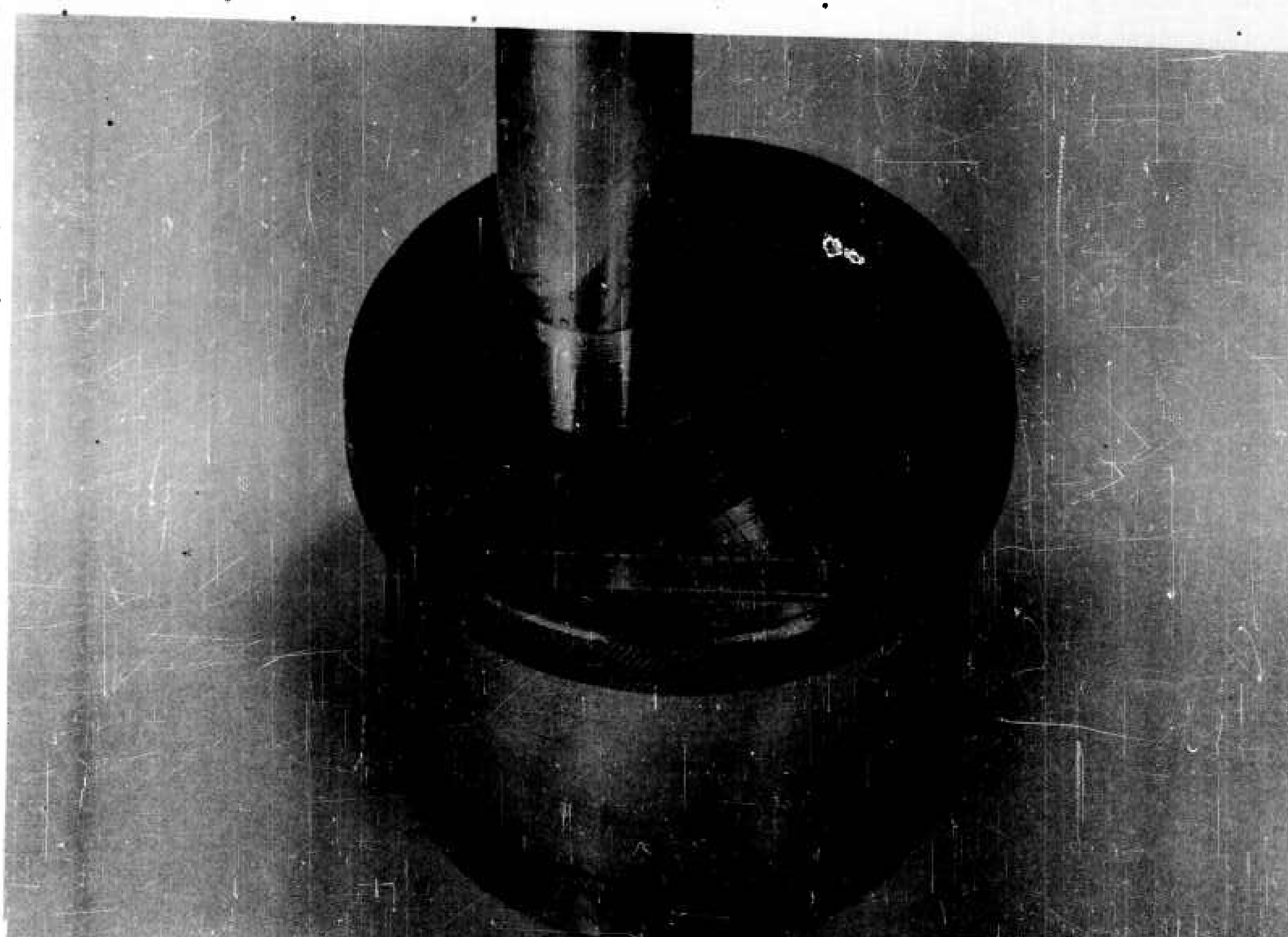

Figure 4. Flat tool and rotatable pedestal for grinding glass substrates to extreme thinness.

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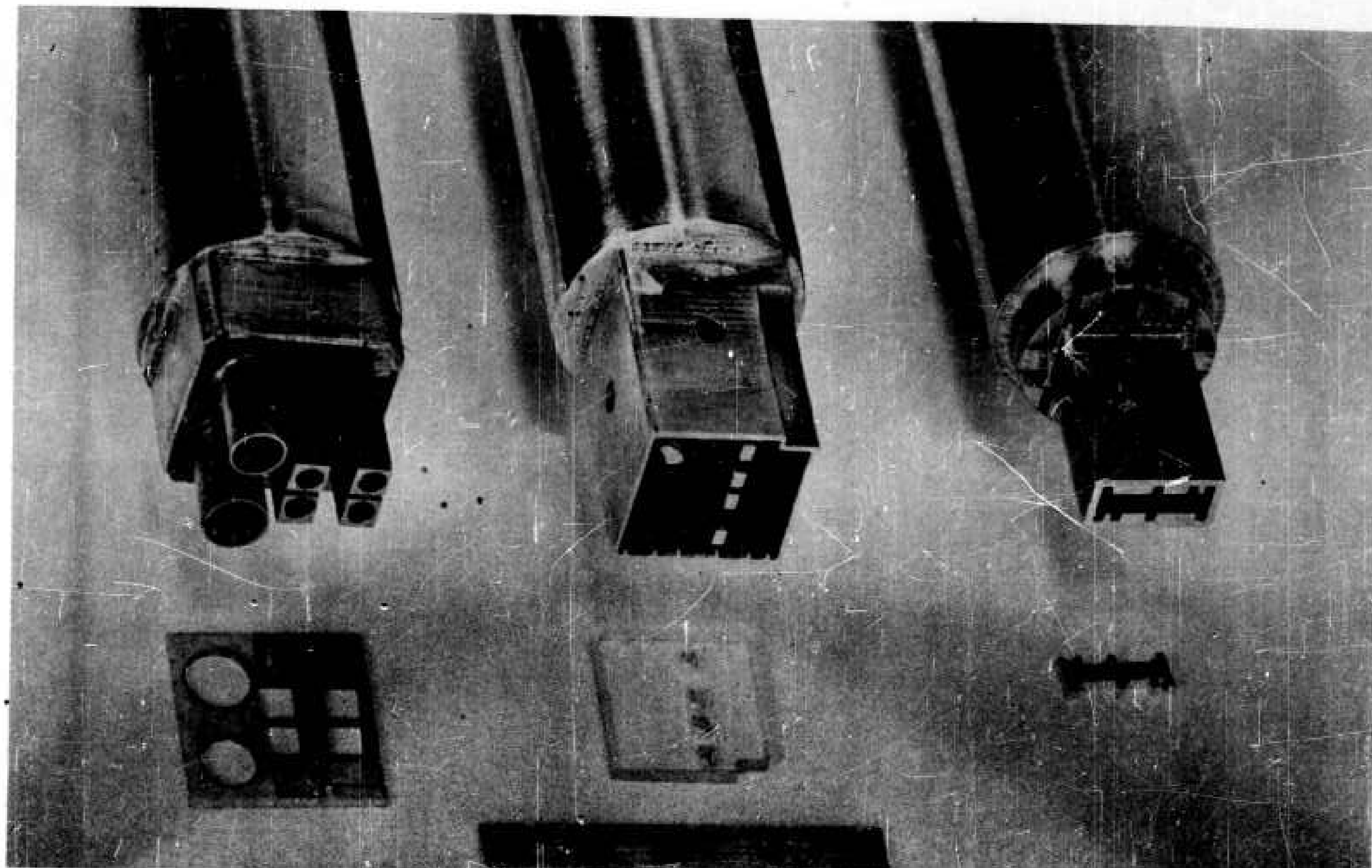

Figure 5. Tocls employed in impact grinding, and resultant wcrk.

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in a metal plate. This plate was attached to the work table to obtain identical placement of pieces for successive production.

The full power of the machine was applied at a pressure of 12 oz. Slurry containing No. 320 grit was applied across the work piece from a single nozzle. Thirty-five seconds were required to cut through the 0.020-in. ceramic and extend the cut into the glass backing plate to insure accurate dimensions. There was less than 10 percent breakage of these fragile sections. Tool resharpening was required after grinding about 30 pieces.

4.3 Forming outside dimensions and included holes simultaneously.

This job required 0.500-in. square and 0.050-in.-thick glass plates with six notches, 0.015 in. by 0.020 in. across one edge, and four rectangular holes, 0.040 in. by 0.062 in. side-by-side across the plate. One corner of the plate had to be cut out. Close tolerances (±0.002) were required and it was also necessary that the finished pieces have no surface scratches or haze. The tool and product are shown in the center of figure 5

The sides of the tool plate were squared off to make a pedestal 3/16 in. in height around which the sides of the tool could be set. A slot of the width of the rectangular studs was milled to a 1/8-in. depth across the tool plate for future use in positioning the studs.

The four studs were formed in a single piece of flat 1/16-in.-thick ground tool steel by milling through it to produce a four-tined fork. The length of this piece was about 0.6 in. The unmilled end of the piece was inserted in the slot milled across the tool plate.

The two plain sides of the tool were cut out of ground tool steel. The side having the six ribs for cutting the six notches was formed by milling slots in a thicker piece of ground tool stock. The side containing the cut-out corner was formed by milling part way down the inside and part way down the outside of another piece of ground tool stock, as can be seen by inspection of the upper side of the tool in the center of figure 5.

The tool was assembled by placing the tool plate on the tip of the upturned tool holder, positioning the piece containing the studs in the milled slot, placing the sides around the tool plate, and clamping the assembly together. The whole assembly was brazed in one operation; the silver-solder was applied entirely from the outside and drawn in by capillary action. The assembled tool was ground to insure plane cutting surfaces.

When the first pieces were turned out and removed from the backing plate, it was found that the under side was cloudy around the cut edges. This was apparently due to the fact that some of the slurry in the holes worked its way in between the work piece and the backing plate, abrading the surface in this zone. These roughened spots rendered the pieces unsuitable for subsequent use as substrates for vacuum deposition. Wax-saturated paper was inserted between the work and the backing plate and was used to join the work to the backing plate. It solved the problem of migration of slurry.

Full power at a pressure of 8 oz was used for this operation. With No. 320 grit, 45 sec were required to cut through the glass. It was found that, after about 12 pieces had been made, the thin ribs forming the edge-slots wore to a point where the tolerances required could no longer be retained. The tool was then resharpened by grinding until the worn portion was removed; no special support of the tool components was needed during grinding.

4.4 Female tool for forming rectangle with eight fingers:

This job required a tool that would cut a Hall measurement specimen from semiconductor material. The shape of the Hall specimen which can be seen in figure 5, right, was that of a rectangle with eight small fingers. The tool was formed from four separate side pieces brazed together. However, the slots for producing the fingers were all milled down a single long piece which was subsequently cut in half. In this way, the required symmetry of these fingers was assured.

The tool plate was milled to contain a raised rectangular pedestal (figure 6), around which the sides of the tool were set, and grooves which helped in assembly and alignment. Prior to brazing, a steel block was dropped down into the closed end of the tool, and a carbon block was inserted part way into the open end, to assure alignment of the fingers during brazing. After brazing, the carbon block was removed but the steel block remained in place.

The material to be formed by this tool was 0.030-in.-thick semiconductor material of fragile nature. For this reason, the power control knob was set at only one-third of full travel and only 3 oz of pressure was applied. Even so, 20 sec were sufficient to make the piece, and ±0.001-in. tolerances were maintained. No. 320 grit was used. Glass was used for the backing plate.

4.5 Cutting doughnuts

This job required the fabrication of microminiaturized toroidal coil-forms from 0.015-in.-thick ferrite stock. These coil forms are pictured in figure 7. The dimensions of the one on the left were 0.025 in. ID and 0.050 in. OD; the dimensions of the one on the right were 0.015 in. ID and 0.030 in. OD. Surgical steel tubing was used for the outer cutting component of this tool and drill rod for the inner cutting component.

In making the larger of the two required tools, a brass tool plate was first brazed to the tool holder. Concentricity between the inner and outer component was accomplished in the following manner. The brass tool plate was drilled to accept a piece of drill rod of the required diameter (less double the grit size) and was also turned to form a shoulder part way down

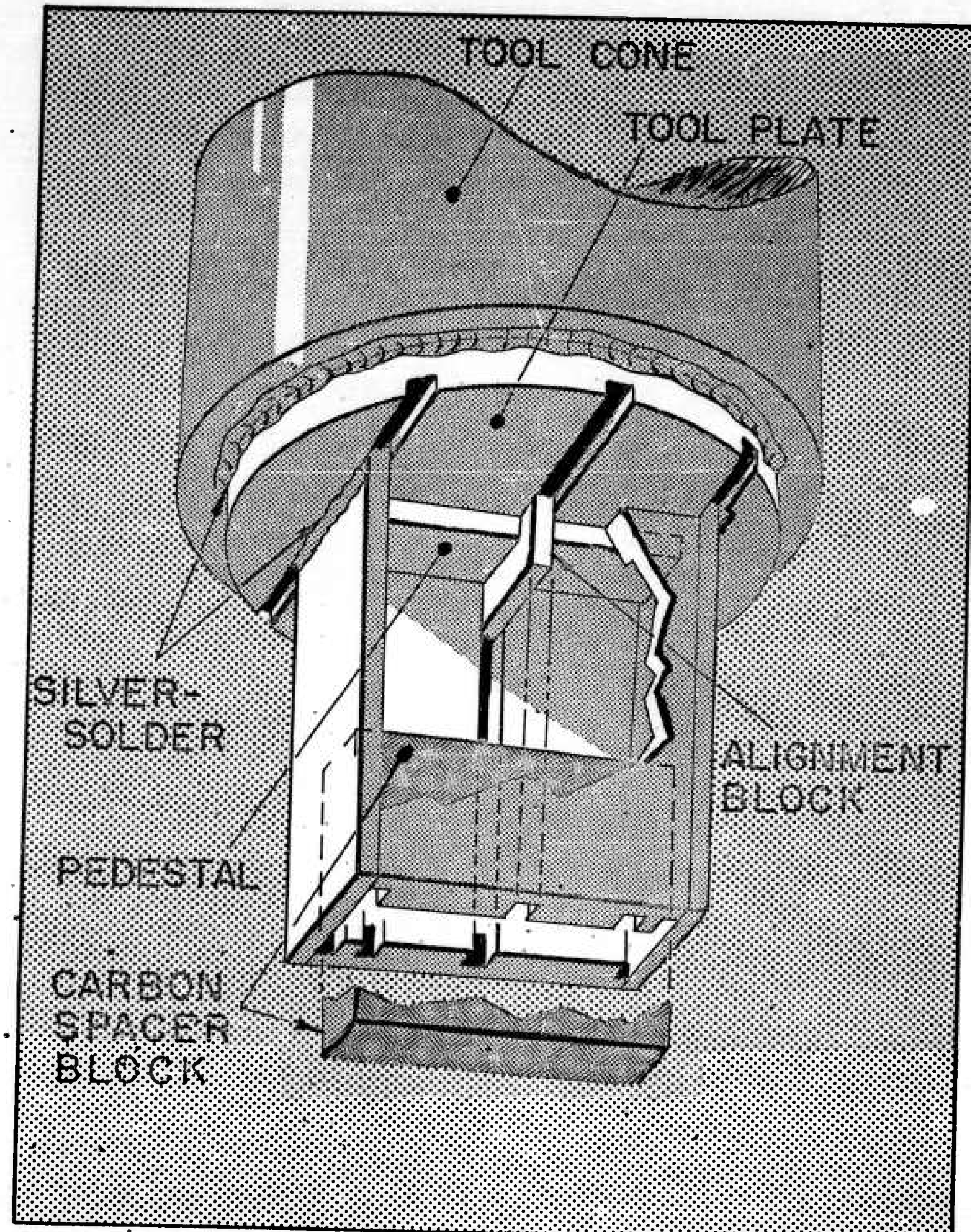

Figure 6. Fabrication details of tool employed in impact grinding of Hall measurement specimens (see Figure 5 - right).

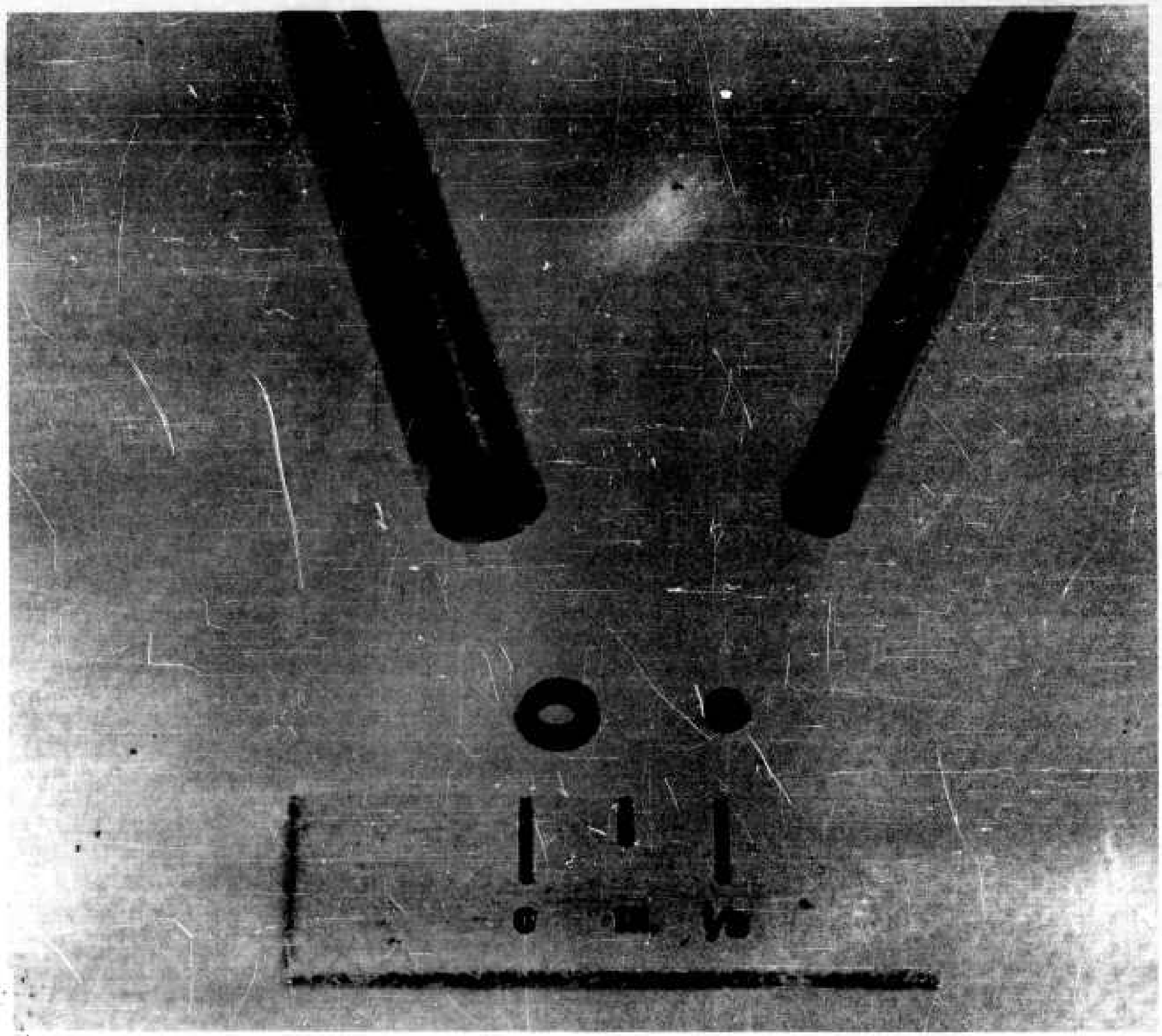

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Figure 7. Tips of tools (top) employed in ultrasonic machining of tiny toroids (bottom).

the sides of this plate. The diameter of this shoulder was the same as the ID of the steel tubing. The drill rod and the steel tubing were then positioned on the tool plate, and aligned at their extremities by means of a suitably drilled cap. The whole assembly was positioned on the tool holder, and all remaining brazing was done in one step.

In making the smaller of the two tools, all brazing could not be done in one step because the thin walls of the tubing and small diameter of the rod tended to promote breakdown of these components during brazing, and deviations from concentricity. The tool plate was first brazed to the tool holder. This plate was then drilled to accept the inner cutting component and then the drill rod was brazed in place. Next, the shoulder was turned, the outer steel component was positioned over the shoulder, and this component was brazed in place, using a suitably drilled cap at the extremities to aid alignment.

Wax was used to secure the ferrite to the glass backing plate. Due to the small dimensions and the fragility of the tool, only one-third of the machine's power was used at a 3-oz pressure. Each piece was made in 10 sec, with breakage limited to 5 percent.

It was necessary to support the inner and outer tool components during sharpening by filling the space between them with wax, which was subsequently melted out.

4.6 Array of 100 holes

This job required 100 holes, 0.016 in. in diameter on 0.031-in. centers, in an 0.015-in.-thick ceramic material. The holes had to be uniformly spaced and parallel.

The first problem was spotting and drilling the 100 holes in the tool-plate intended to receive the studs. This plate was made of 1/32-in. thick brass because the machining properties of brass simplified the drilling of these tiny holes. An engraving machine was set for a 10-to-1 reduction and a plastic positioning plate having the holes at 0.310-in. centers was prepared. Using this positioning plate, spotting the 100 holes in the brass plate with a pivot drill, and then drilling them to a diameter of 0.0135 in. in a sensitive drill press, became a repetitive process.

Next, a well was milled in a larger steel tool plate and a shoulder was formed to support the smaller drilled tool plate. The well was 1/32 in. deep below this shoulder. This larger tool plate was then brazed into position on the tool holder.

Drill rod, 0.0135 in. in diameter, was cut into 5/16-in. lengths. The pieces of rod were inserted in the drilled tool plate and allowed to protrude slightly at the back of the plate so that they could readily be soldered in place there, as well as at the front surface. This plate was forced firmly against the shoulder of the larger tool plate. Then both the drilled plate and the 100 rods were soft-soldered in place (fig. 8).

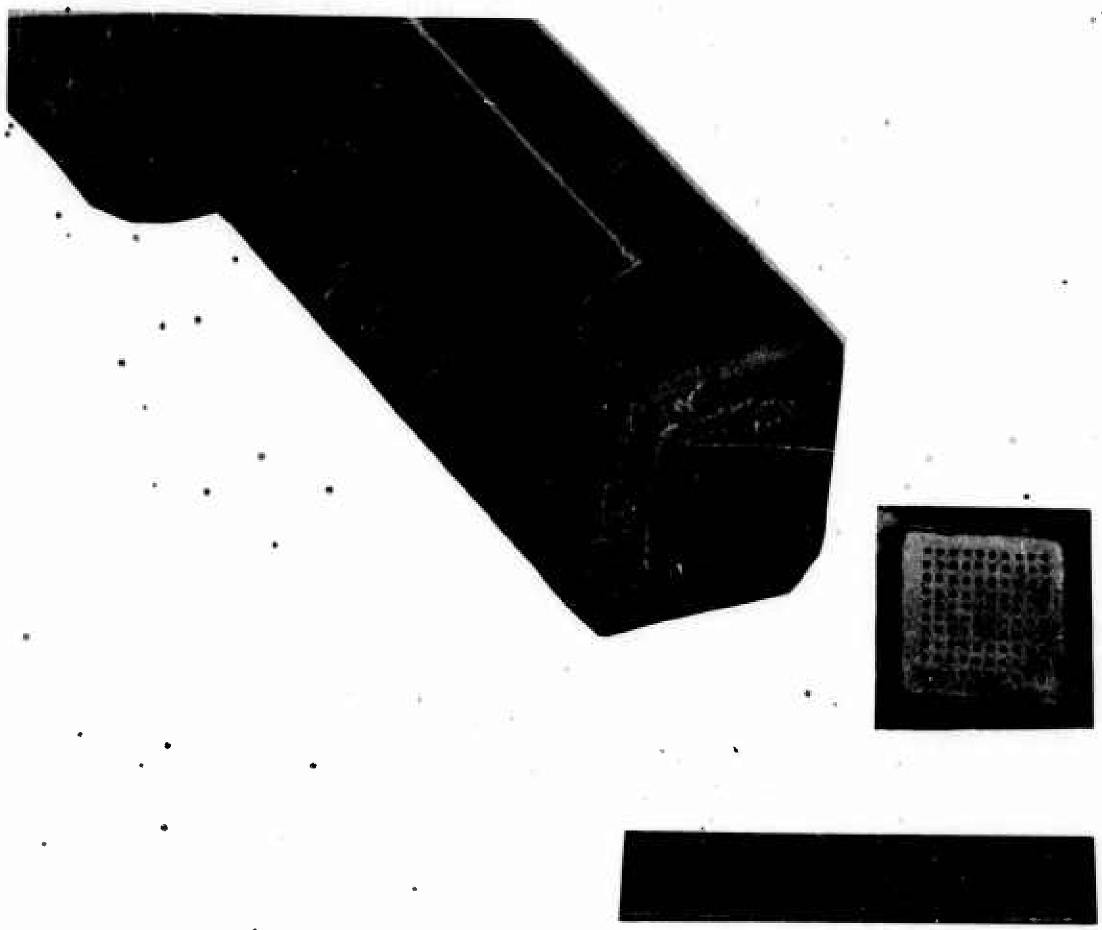

Figure 8. Tool (left) for fabricating 100-hole substrate (right).

The tool was sharpened by grinding. It was necessary to support the fragile rods with wax which was retained, while molten, by an adhesive-tape dam around the large tool plate. After the wax hardened, the tool was sharpened, and then the wax was melted off.

The fragile nature of the work piece and tool restricted the power setting to one-half the machine's maximum, applied under 6 oz of pressure. Less than 1 min was required to drill through into the glass backing plate.

4.7 Array of ten holes 0.470-in. deep

In this job, it was necessary to drill an array of ten holes 0.016-in. in diameter into a piece of glass 0.470-in. in thickness. The depth of drilling presented a problem that was greatly complicated by the small diameter of the holes. The major problems lay in maintaining a flow of slurry at the cutting surface and maintaining the desired spacing. The difficulty of this job was compounded by the narrow (0.048-in.) width of the glass used.

The flow of slurry was maintained by designing the tool to permit feeding the slurry into the tool holder at its node, then down a drilled channel to the tool, and finally through hollow studs to the cutting surface at the bottom of each hole. A drawing of the tool appears in figure 9.

In this case, as in the tool for making the array of 100 holes, two tool plates were used. The larger plate was made of steel, and was brazed to the tool holder, and chucked in a lathe. Then there were drilled in this piece the central hole for passage of slurry, the transverse hole at the node, a channel across the position to be occupied by the hollow tubes, and a recess to fit the drilled tool plate.

The smaller tool plate was made of brass. Again, a pivot drill in an engraving machine was used to spot the holes, and a small, high-speed drill-press was used to drill them through the 1/32-in.-thick brass plate. The same technique was used to drill identical holes through a small brass drilling jig which had been milled to slip over the sides of the glass work piece.

A readily available source of hollow studs of useful dimensions was found in commercially available stainless steel tubing of 0.014-in. OD and 0.007-in. ID. The tubing was inserted in the ten holes in the brass plate in lengths permitting a protrusion of 0.600 in. beyond the front surface of the plate and 0.031-in. beyond the back surface of the plate. The protrusion at the back surface was required to prevent solder from entering the bores of the studs during the soldering operation. In order to align the studs, the previously mentioned brass jig was mounted over the long ends of the studs and was supported at their extremities. Soft solder was flowed around the stud-plate interfaces to fuse the tubes to the brass tool plate. Subsequently the brass tool plate was soft-soldered to the steel tool plate.

In the drilling operation, the studs were inserted in the holes in the brass jig, and this jig was then fitted down over the edge of the glass work

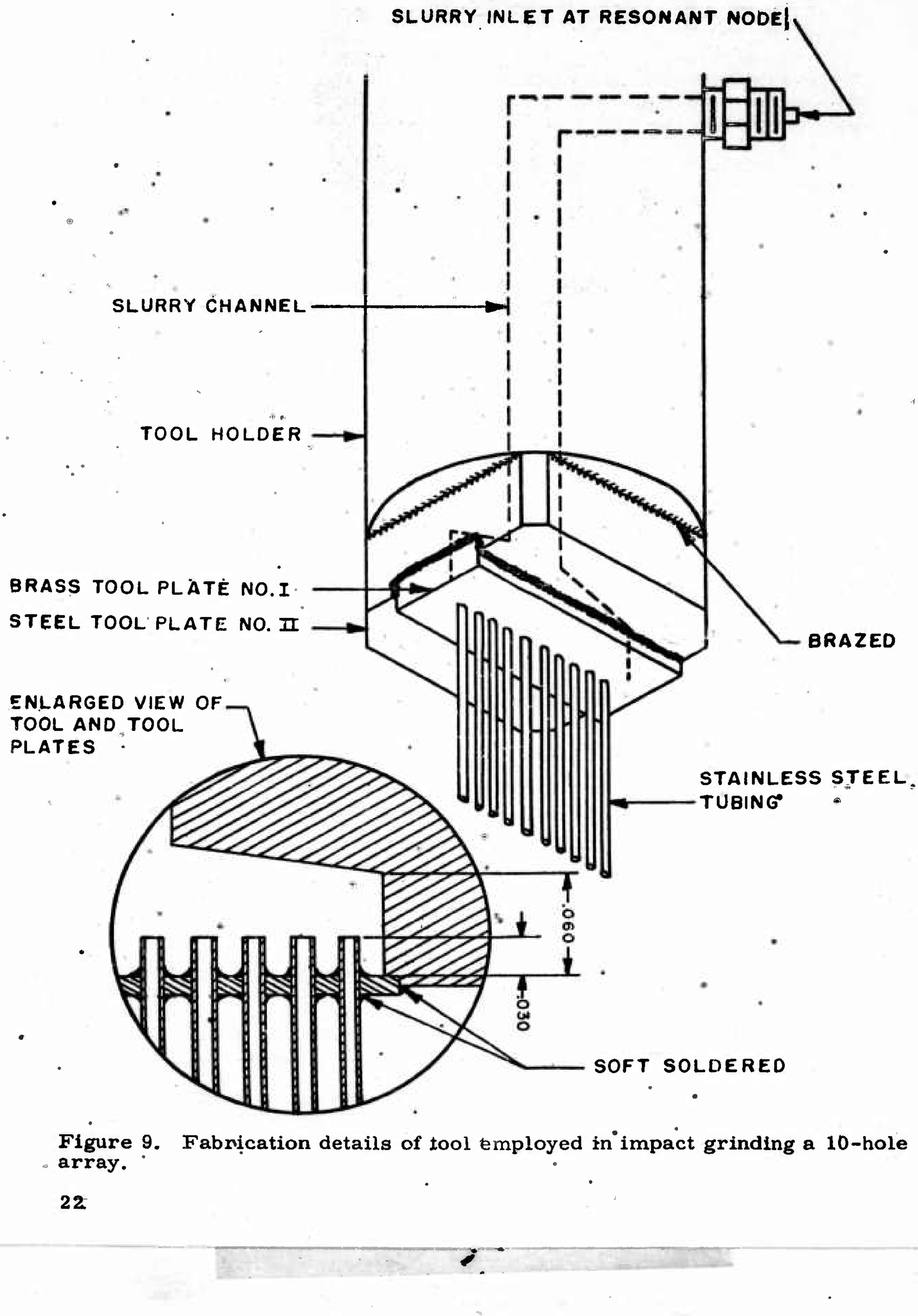

Figure 9. Fabrication details of tool employed in impact grinding a 10-hole array.

piece. No. 600 grit, which has a particle size diameter of only 0.0005 in., was used in grinding to aid flow through the tubing. The power control knob was set at about one-third full travel, and the pressure at 5 oz. At 0.030-in. penetration, the tool was raised to permit the removal of the brass jig and the tubes were carefully reinserted in their original holes. The initial rate of penetration was about 0.050 in./min but, after the first minute of operation, this rate decreased to about 0.0125 in./min where it held constant for the remainder of the operation.

Upon completion of the operation, it was found that fingers of glass remained in the bores of some of the tubes. There was a 0.025-in. difference in depth between the shortest and deepest holes. Travel as indicated on the depth penetration dial was 0.530 in. while the average true depth of penetration was 0.470 in. The difference of 0.060 in. was due to tool wear. Two of the holes in the work piece had deviated slightly from center but not enough to break out of a side or into an adjacent hole.

Before sharpening this tool, wax was poured around the studs. The wax was confined by metal tubing slipped over the tool and onto the tool holder.

4.8 Spiral-slotted ferrite coil form

It was required to cut a 0.020-in.-deep spiral in a 0.125-in.-thick ferrite slug to be used as a flat core for inductors and transformers in research and development programs. The tool consisted of two bands of clock spring wound together, one a spacer and the other a cutter. The spacer was 0.312 in. in height and the cutting tool 0.625 in. The tool and a finished piece are shown in figure 10.

The spiral was wound around a 0.125-in.-diameter rod in a lathe. The first four turns had to be heated to make the springs wind evenly around this small-diameter rod. The spacer was left in a normal state while the cutting coil was annealed. This procedure tended to push the cutting coil out and to make it wind evenly. After making the required number of turns, the bands were wrapped with wire.

A tool-holding cap was made to fit the outside diameter of the wrapped coils. Silver brazing alloy in sheet form was laid in this cap, the wrapped coils were set in the cap, similar brazing sheets were laid on top of the tool holder, and the cap was then set upon the tool holder.

All the parts were then brazed together by induction heating. It is important to note that brazing must be accomplished at all contact surfaces between the tool and the tool holder in order for the tool to resonate. Also, the entire edge surfaces of the wound springs had to be bonded to their respective contact surfaces in order to eliminate vibration of the springs. Hence, a full flow of solder around the parts to be bonded together is essential.

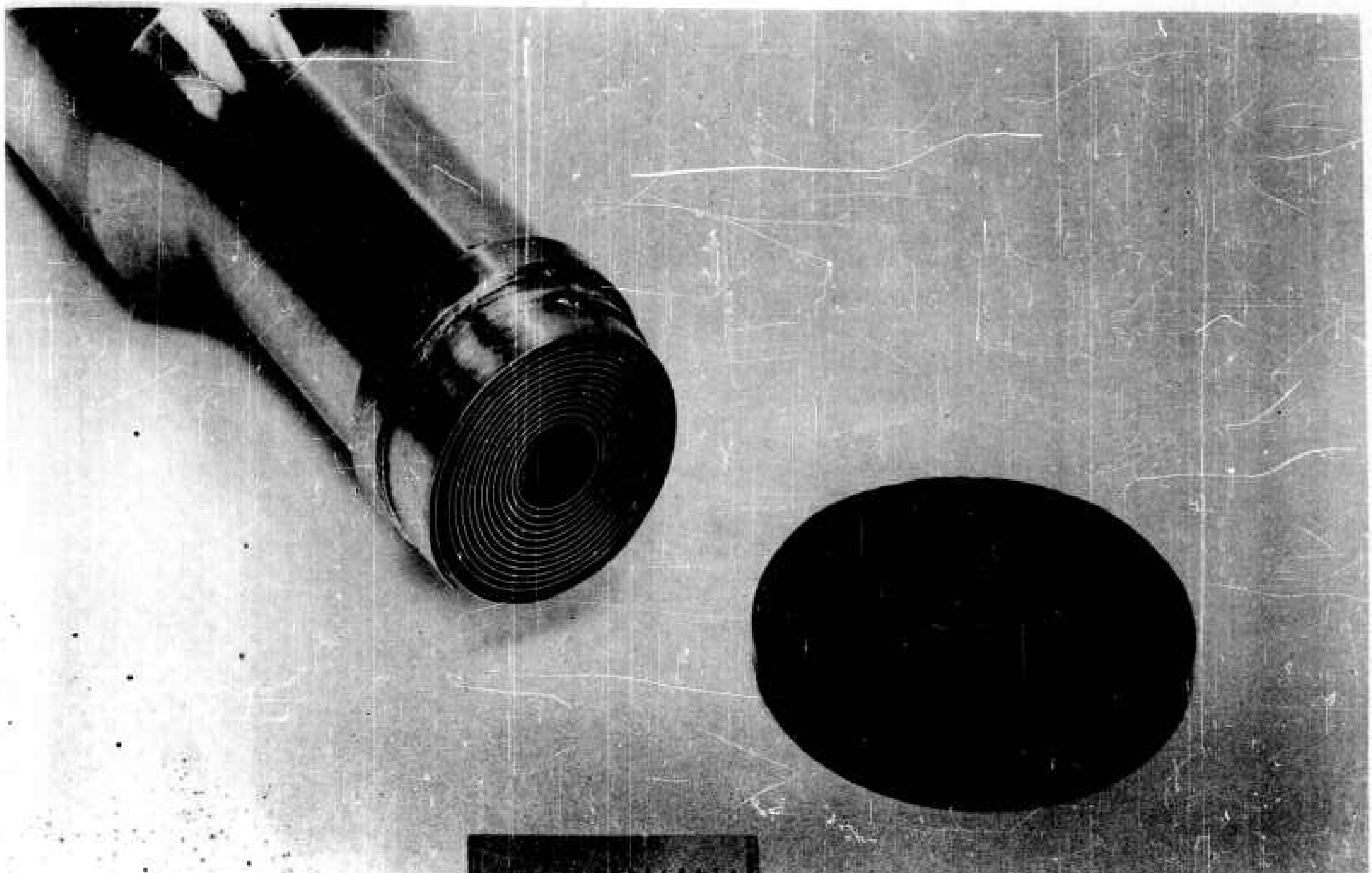

Figure 10. Tool (left) for fabricating spiral groove in ferrite (right).

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After this tool was finished, the requirements for the piece were changed and a larger arbor was requested. Accordingly, the center of the spiral was cut out and then the cutting edge was ground level. The finished grooves were 0.011 in. in width and 0.020 in. in depth. The space between the grooves was 0.016 in. in width. Cutting time was 8 min. per piece. Grit No. 600 was used to aid the flow of slurry under the tool. A pressure of 3 lb was used.

5. CONCLUSIONS

Materials that are best suited for use as insulators and spacers are, in most cases, too fragile to be machinable by conventional techniques. However, the ultrasonic impact grinder has extended the usefulness of these materials into applications requiring close tolerances and special configurations.

In this report, the grinding of fragile materials into extremely thin sections, and the introduction into such sections of holes, cavities, notches, and spiraled grooves has been described and illustrated.

From a variety of applications described it is evident that ultrasonic impact grinding techniques have become invaluable in the pursuit of research and development projects.

6. ACKNOWLEDGMENTS

The author is indebted to C. E. Swann for suggesting the use of clock springs in the fabrication of the spiral cutting tool pictured in figure 10.

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